SuperSymmetry 2011(SUSY11)
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FermiLab

# Searches For H→WW→$\ell\nu\ell\nu$ and VH→VWW→like-sign dileptons

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# Higgs Searches at Tevatron

Higgs production cross-sections at Tevatron:

**-- gluon Fusion ($\sigma \approx 0.2$ -1.0 pb)**

**-- Z/WH production ($\sigma \approx 0.01$ - 0.3 pb)**

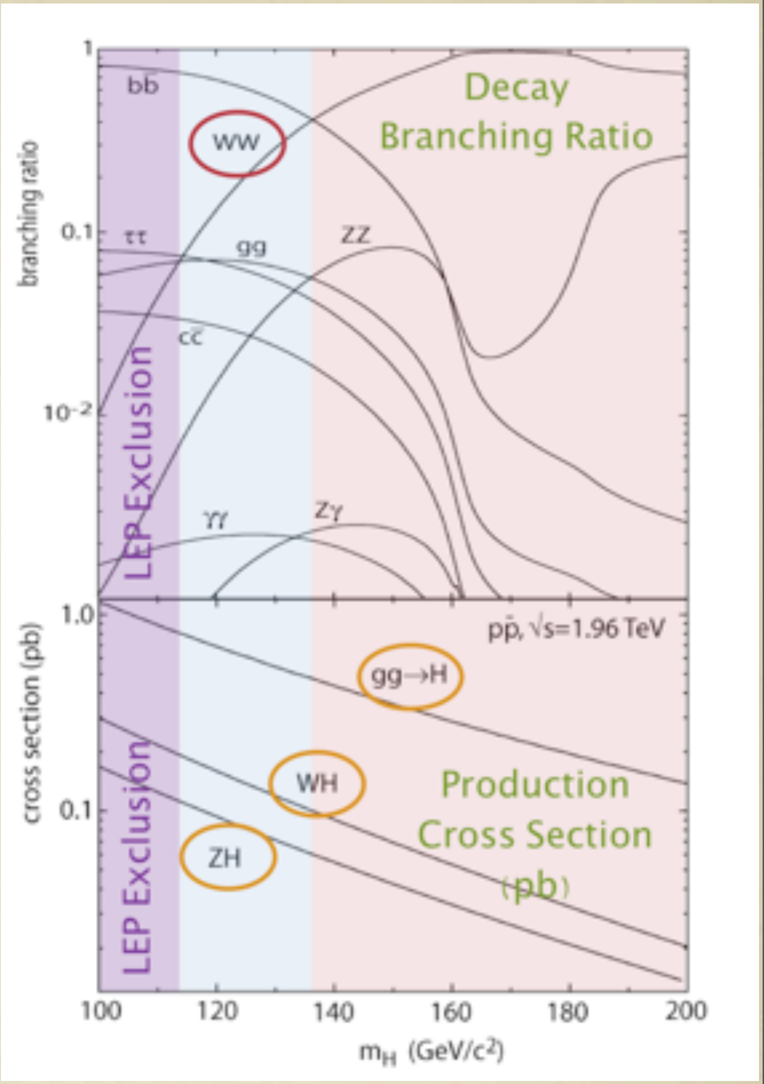
**-- Vector Boson Fusion (VBF) ($\sigma \approx 0.01$ - 0.1 pb)**

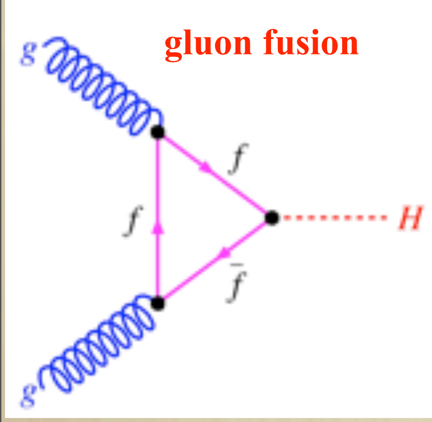
For maximal sensitivity to the Higgs Signal, all production modes considered.

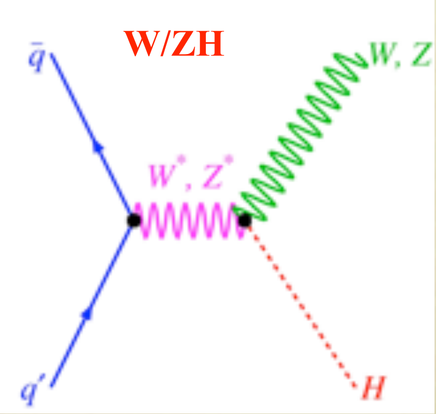
Gluon Fusion is the most dominant production mode

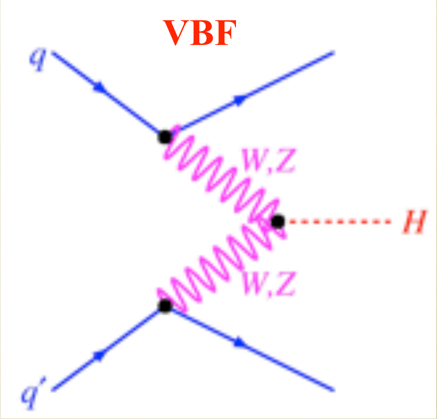
High Mass Higgs Searches, $m_H$ >135 GeV.

**-- Dominant decay mode is $H \rightarrow WW^*$**

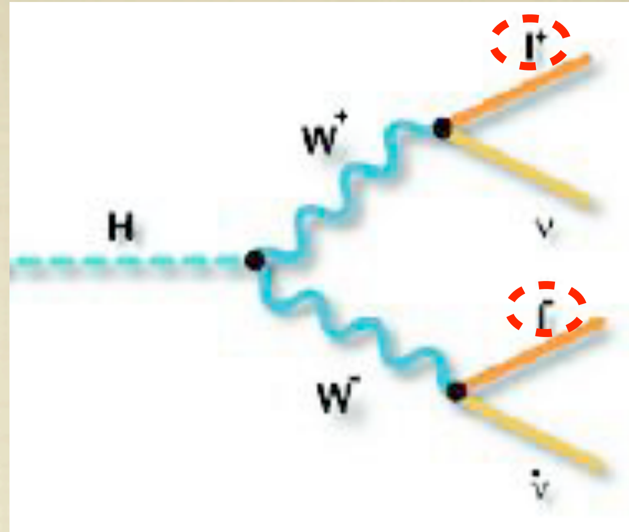


# The Analysis Strategy




- Large hadronic background, requires leptonic decay mode of W boson as a handle.

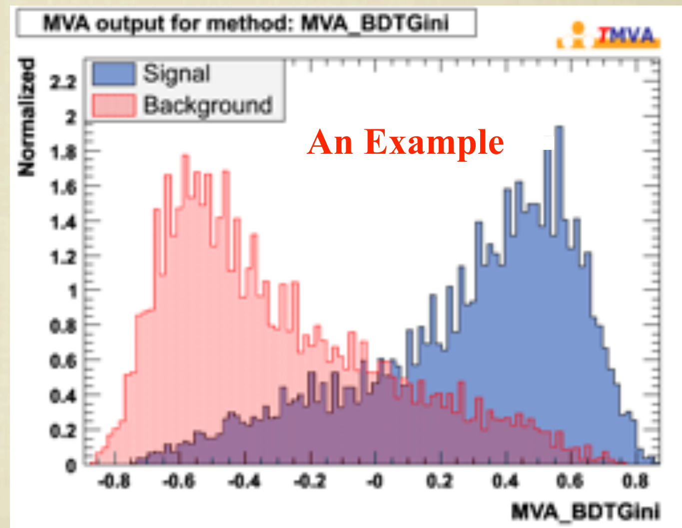
- S/B is quite small (<1%), even at final-selection.

  ***-- Hence cut-based analysis not possible!***

- So, perform multivariate analysis to reduce the background & extract signal.

  ***-- Use as many discriminating variables.***

  ***-- Output of MVA used to search for signal.***




***Divide & Conquer!***

- Split into many final states.

  ***-- optimize each final state to gain maximal sensitivity.***

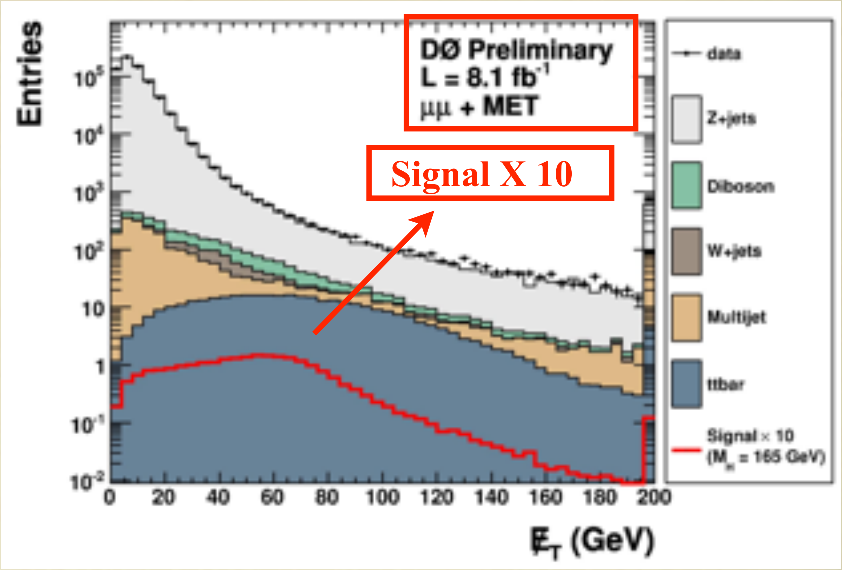
  ***-- All final states treated separately while computing limits.***

# $H \rightarrow WW^* \rightarrow \ell^+\nu\, \ell^-\nu$

* Signal Signature:

- Two opposite sign high $p_t$ isolated leptons.
- High missing $E_t$ due to neutrinos escaping detector.
- Leptons in the final state tend to point in the same direction

  → ***Small opening angle between the di-lepton pair.***

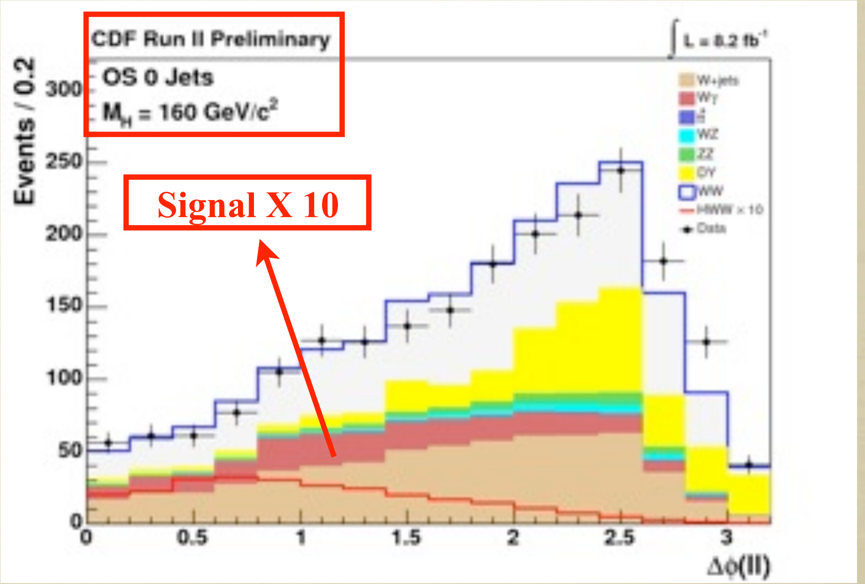



* The final state is split into many sub-channels.

→ ***Event kinematics/topology differ in each final state!***

DØ - lepton flavor.

CDF - lepton flavor/ lepton quality




* Both then finally split into jet bins (0jet, 1jet, >1jets).

→ ***Different S/B composition in the jet bins***

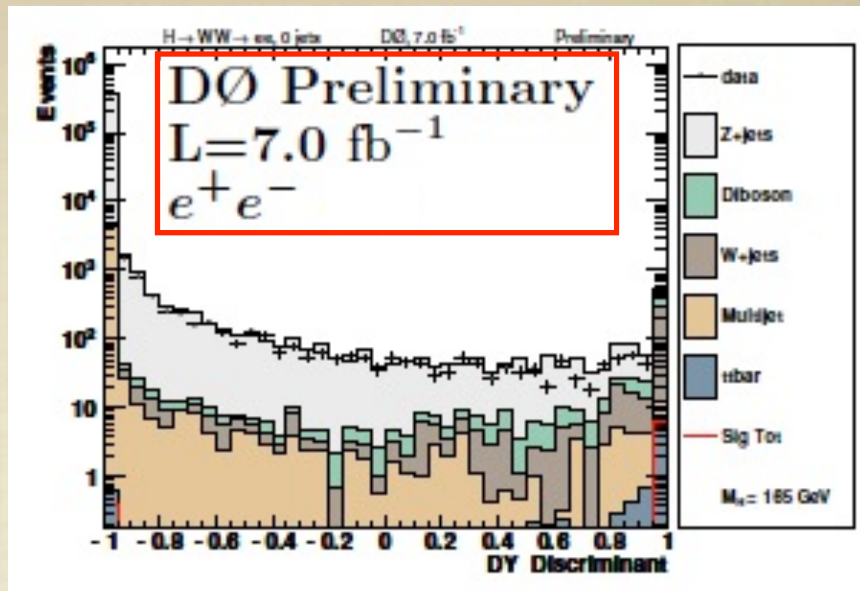
***0-jet WW Vs ggH***

***1-jet W+jets Vs W/ZH***

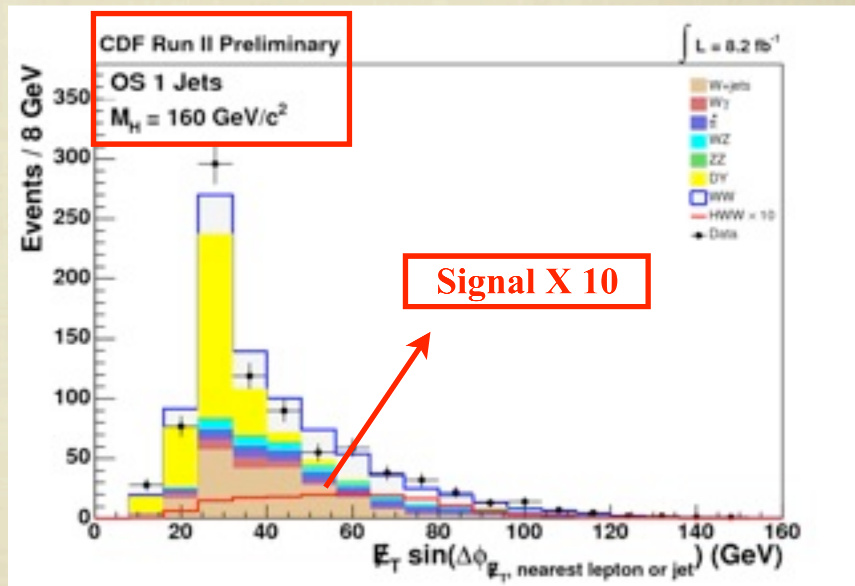
***2-jet ttbar Vs VBF***

# Final Event Selection

* Dominant background at pre-selection, Z/y*
  -- Reduce this over-whelming background
  -- exploit missing $E_t$ in the event.




* DØ uses a dedicated MVA against Z/y* events
  for ee/μμ final states.
  ***-- $E_t$ related quantities used as input variable.***
  ***--Trained in each jet bin/each Higgs boson mass.***
  ***-- Select event with high DT output.***




* CDF, selects events with high missing $E_t$.

$$\not{E}_{T\,\mathrm{spec}} \equiv \begin{cases} \not{E}_T & \text{if } \Delta\phi(\not{E}_T, \text{nearest lepton or jet}) > \frac{\pi}{2} \\ \not{E}_T \sin(\Delta\phi(\not{E}_T, \text{nearest lepton or jet})) & \text{if } \Delta\phi(\not{E}_T, \text{nearest lepton or jet}) < \frac{\pi}{2} \end{cases}$$

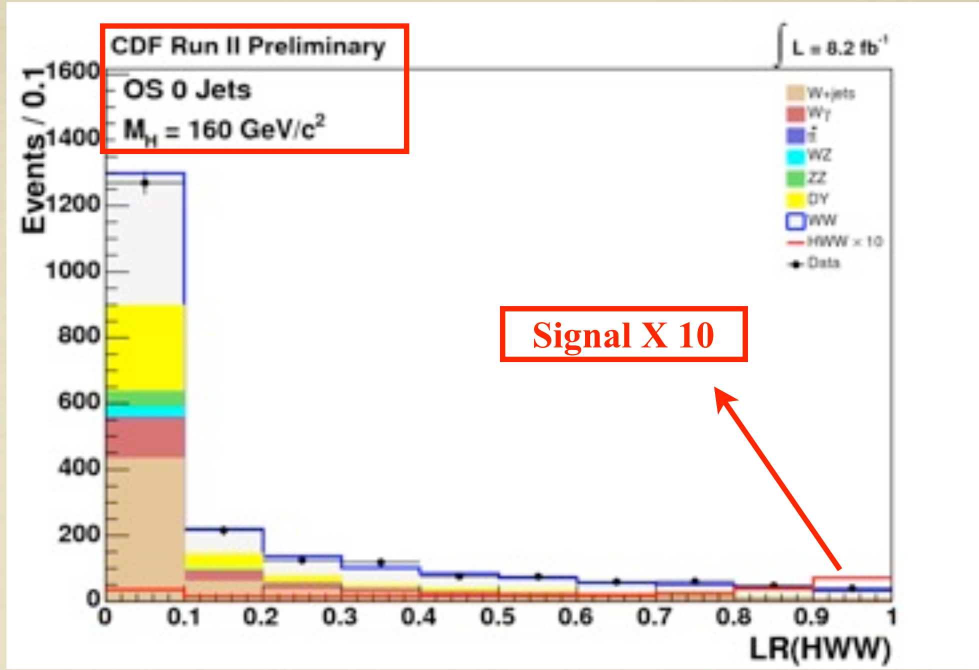
# Extracting Signal

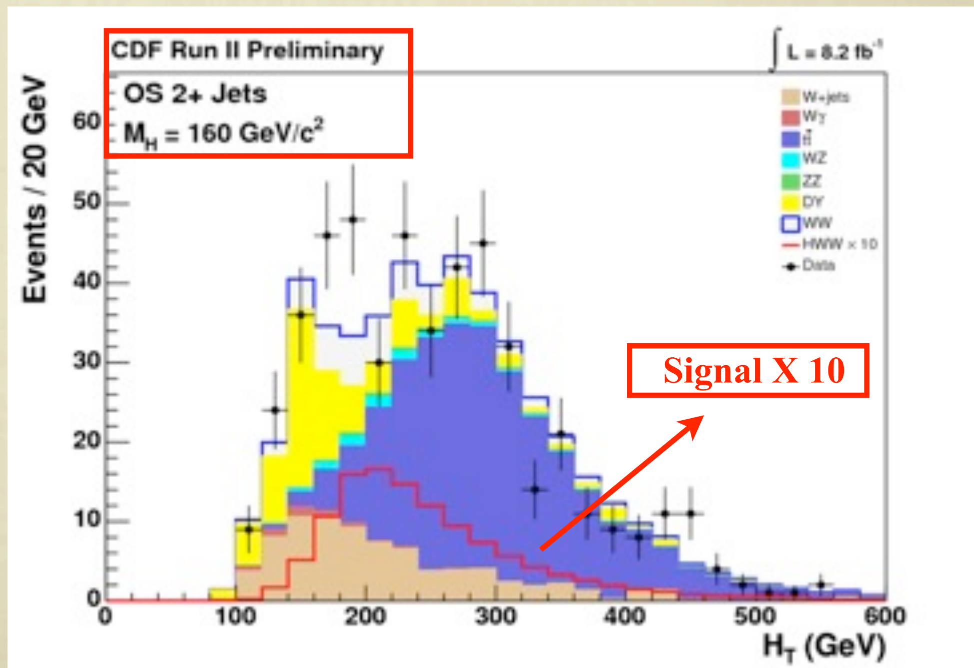
- Train MVA's against the SM backgrounds surviving pre-selection.
  *→ Trained in each jet bin and for each Higgs boson mass point.*

- Variety of inputs to discriminate between Signal & background.
  *→ Construct topological/kinematical combinations.*

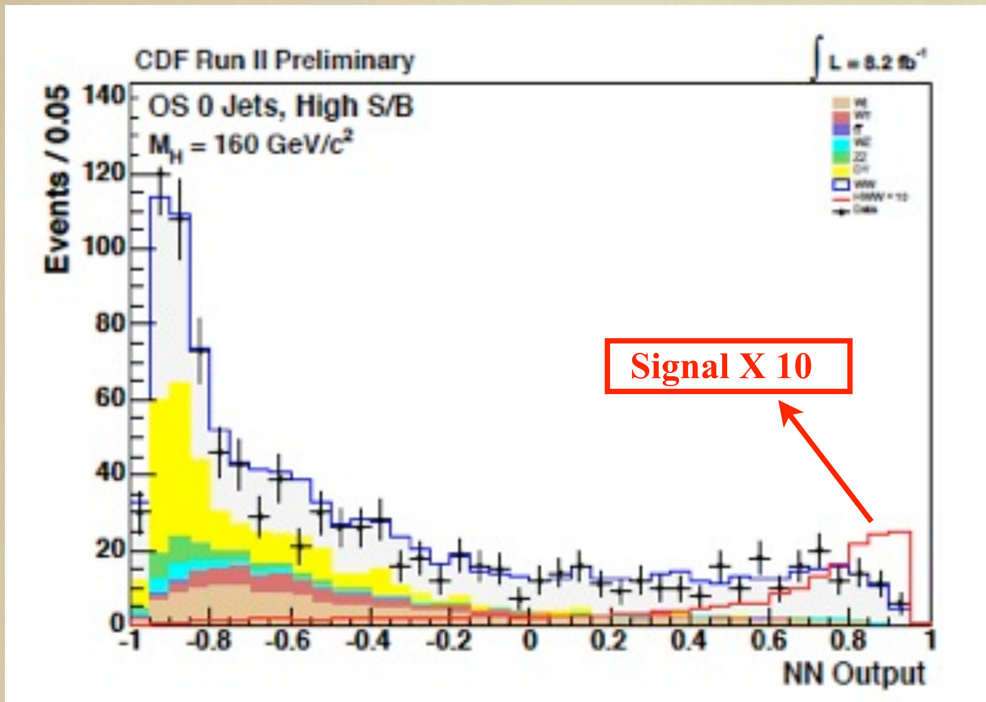
- In general, feed only those discriminating variables as inputs that are well modeled.

- Optimize the performance of these MVA outputs
  in each orthogonal final state.



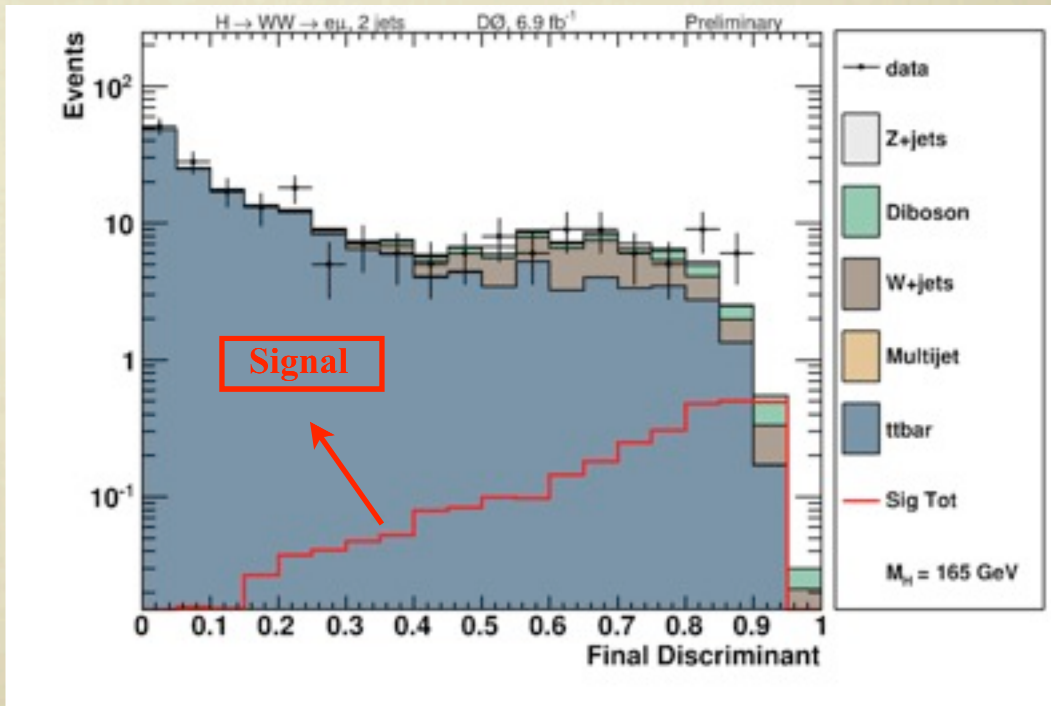



# Output Distributions




• MVA outputs for different jet bins. Signal peaks near “1” where as background is pushed to the lower end of MVA.

- Good agreement between data and expected background prediction.
- No significant excess is observed!



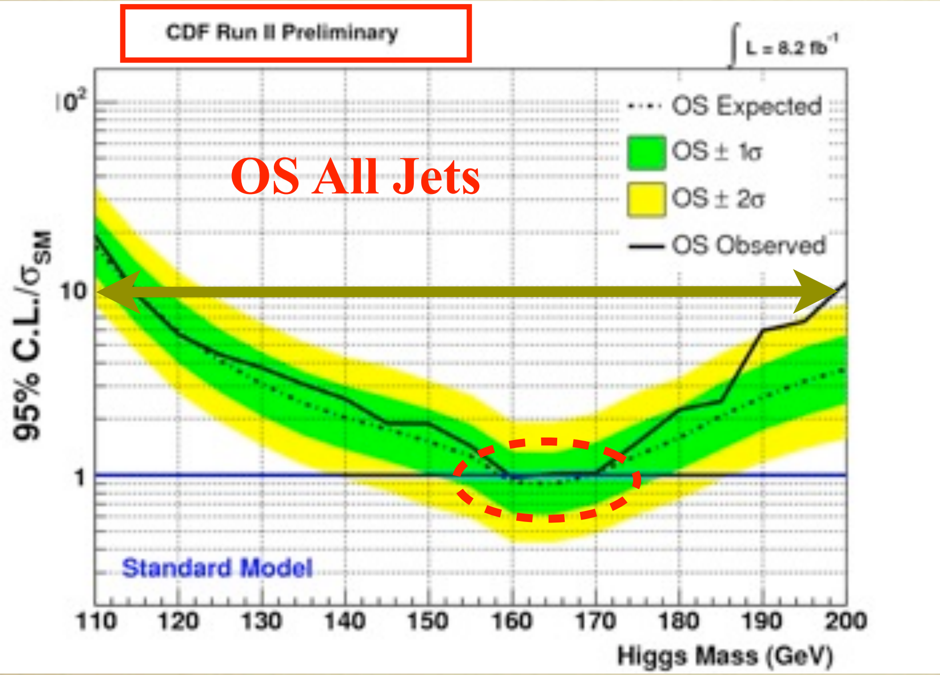
# Setting Limits

• Since no significant excess is observed, hence we proceed to set limits on the inclusive production cross-section $\sigma(p\bar{p} \rightarrow H+X)$ at 95 % C.L.

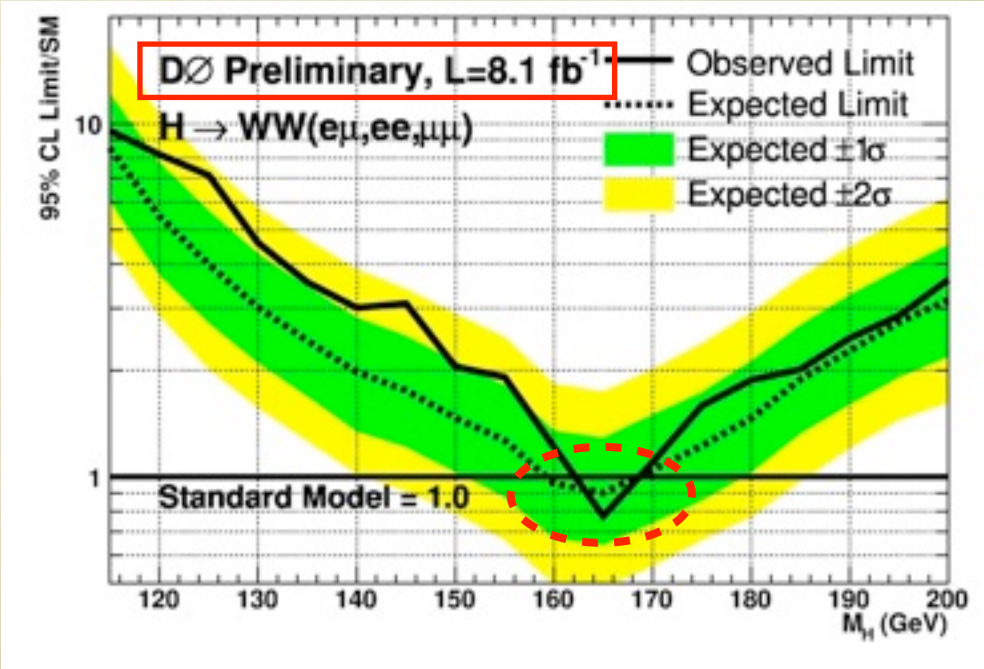
• SM sensitivity at 165 GeV for both experiments. Very nice sensitivity even at low Higgs masses!

| CDF | DØ |
|---|---|
| $m_H$=165 GeV<br>Exp: 0.89<br>Obs: 1.02 | $m_H$=165 GeV<br>Exp: 0.90<br>Obs: 0.78 |

CDF Note 10599 ($H \rightarrow WW^*$ Production), 8.2 $fb^{-1}$

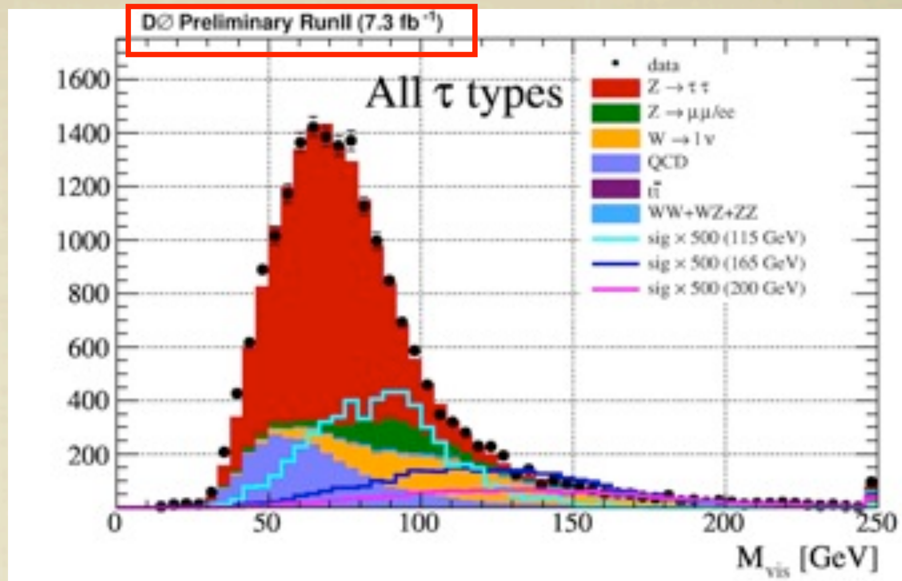



[Conference Note D0 Note 6219-CONF]



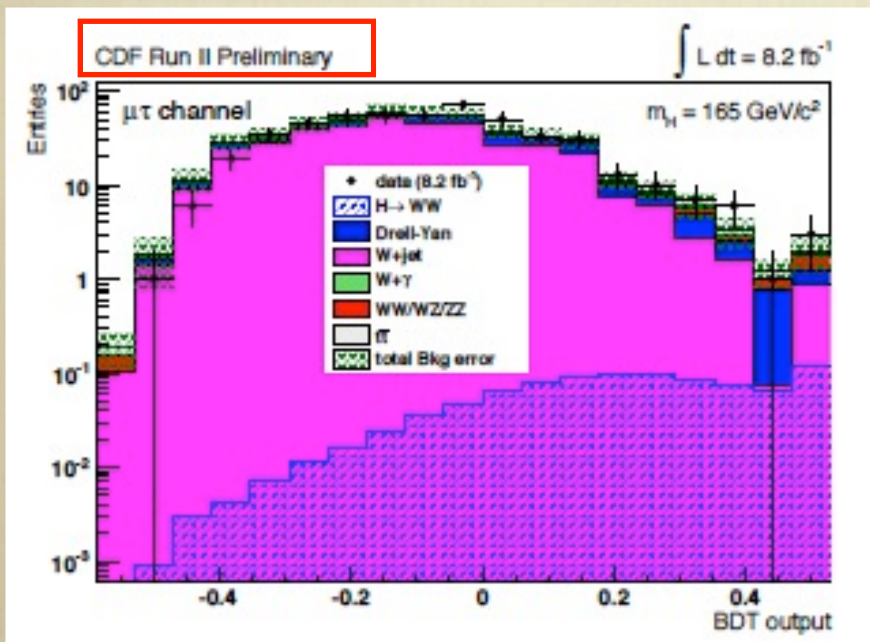
# $H \to WW^* \to \ell^+\nu\,\tau_h\,\nu + < 2$ jets

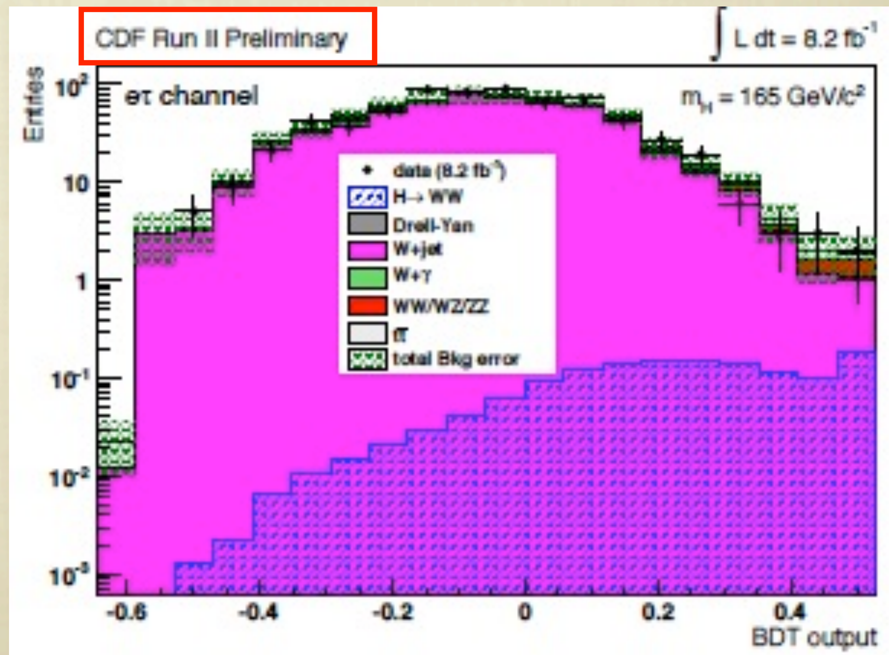
- $\tau$ lepton decays hadronically ~ 66 %.
  - ***→ additional signal events.***
  - ***→ DØ($\mu\tau$) and CDF($\mu\tau$ and $e\tau$) final states.***




- $Z/\gamma^*$, W+jets, Multijet dominates at the pre-selection.
  - ***→ Apply kinematic cuts to reject them.***

- Finally, train a dedicated MVA against all SM background.



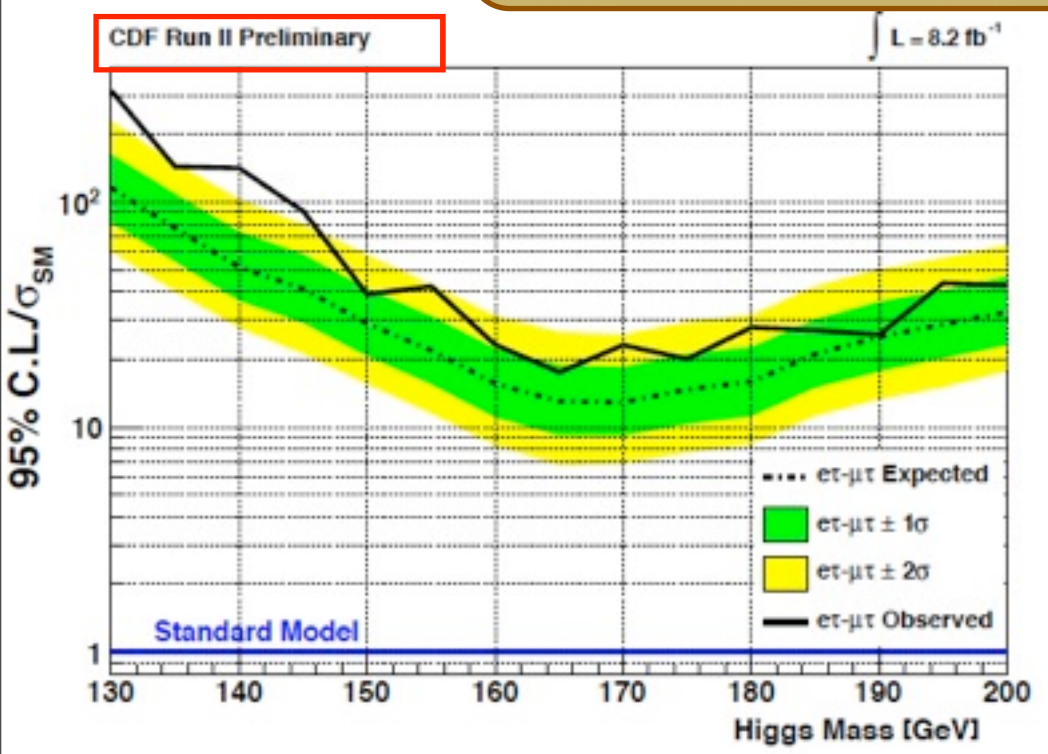



# And the Limits

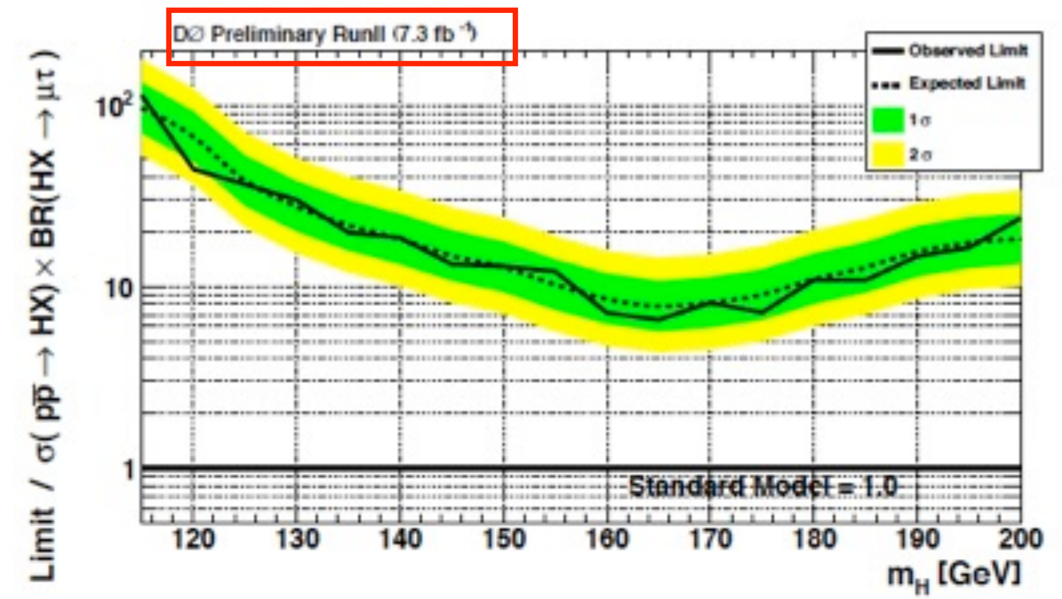
- No significant excess is observed, hence we proceed to set limits on the inclusive production cross-section $\sigma(p\bar{p}\rightarrow H+X)$ * $B.R(HX\rightarrow l\tau)$ at 95 % C.L

| $m_H$ | Exp | Obs. |
|---|---|---|
| 160 | 15.6 | 23.3 |
| 165 | 13.0 | 17.5 |

| $m_H$ | Exp | Obs. |
|---|---|---|
| 160 | 8.5 | 7.2 |
| 165 | 7.8 | 6.6 |

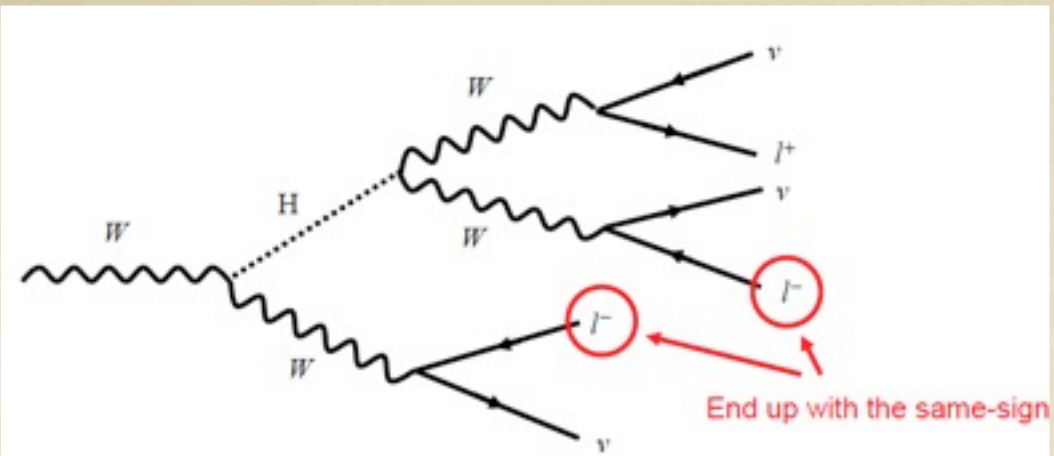



CDF Note 105997 $H\rightarrow WW^*$ Production), 8.2 $fb^{-1}$




Conference Note D0 Note 6179-CONF

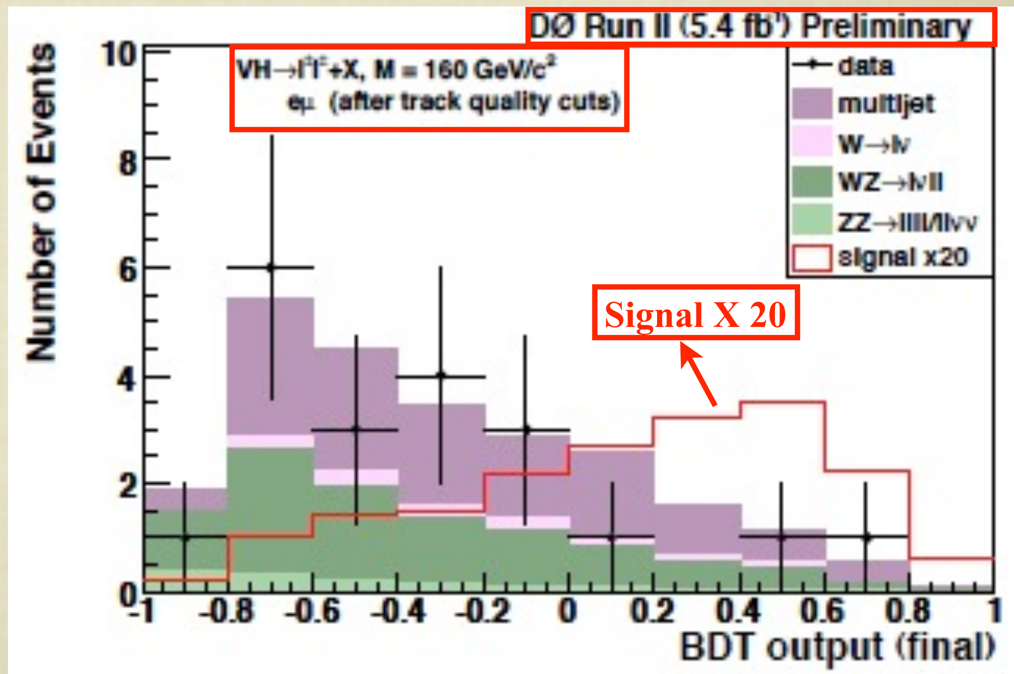
# VH → VWW* → $\ell^+ \nu\, \ell^+ \nu\, \ell^- \nu$



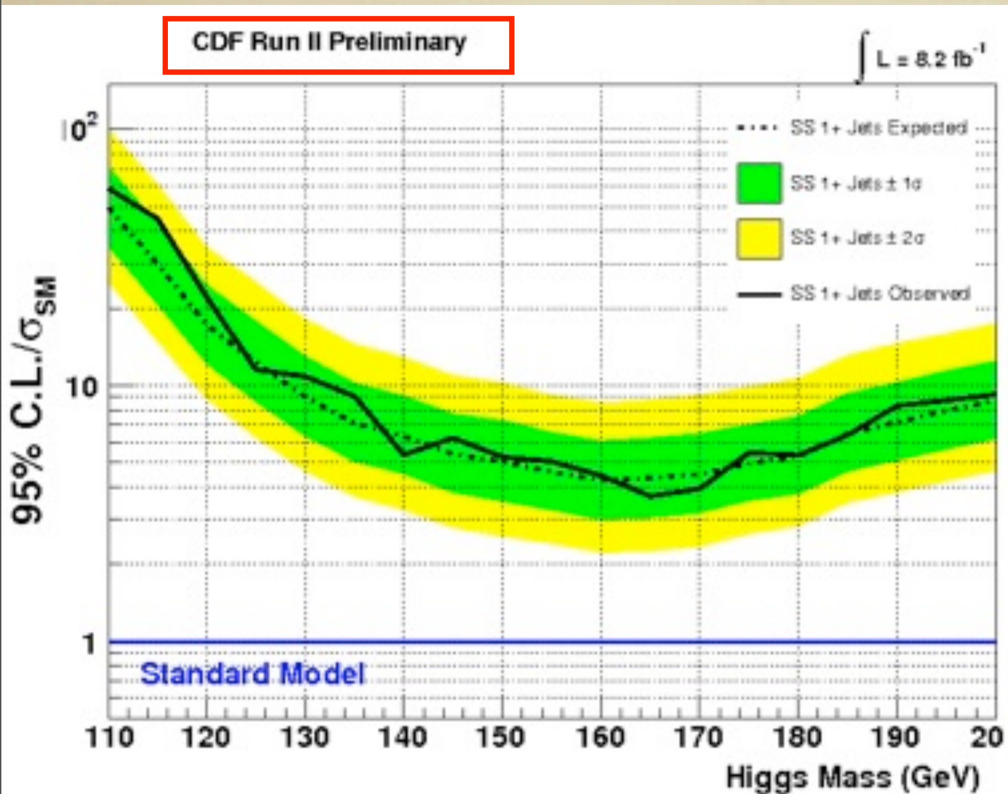

- Multi-leptons and jet in the final state with a like-sign lepton pair.
  → ***suppress the SM backgrounds.***

- Dominant background comes from two sources:
  → ***charge mis-measurement of real lepton.***
  → ***re-construction of fake lepton***

- Construct a MVA for signal extraction.
  → ***Dilepton kinematics***
  → ***kinematics of all the jets in the event.***
  → ***Missing $E_t$***



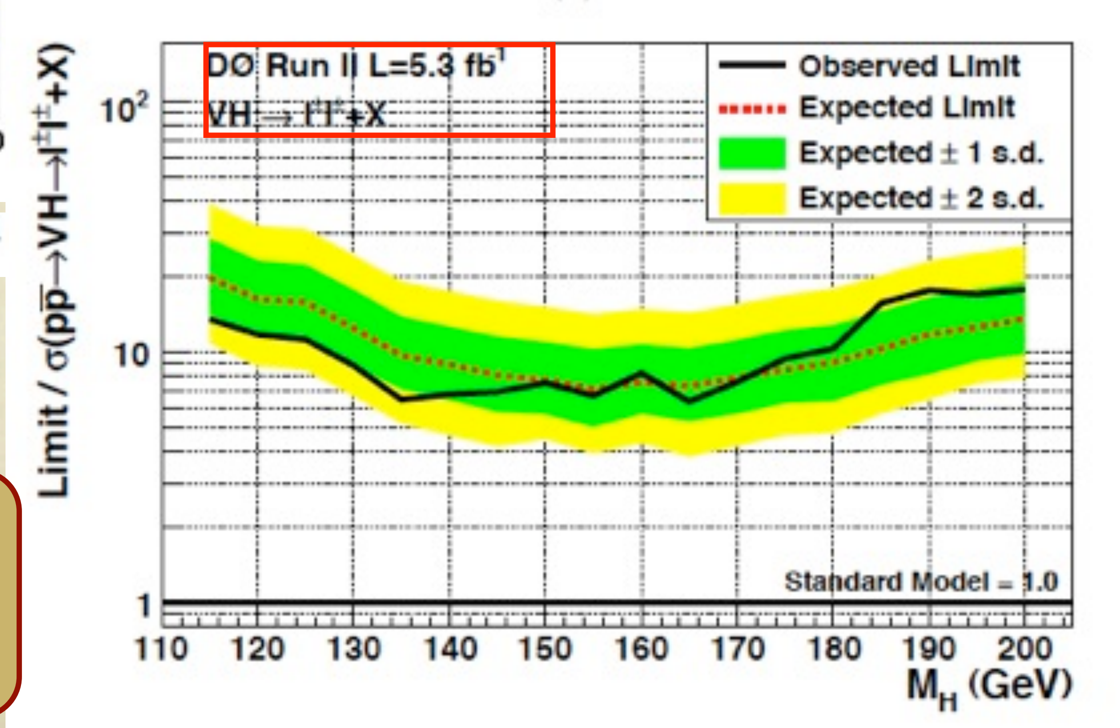
# Finally Limits.




CDF Note 10599 ($H \rightarrow WW^*$ Production), 8.2 fb$^{-1}$

$m_H$=130 GeV
Exp: 9.01
Obs: 10.85

Submitted to Phys. Rev. D (arXiv:1107.1268 [hep-ex]), 5.3 fb$^{-1}$




$m_H$=130 GeV
Exp: 12.5
Obs: 8.8

# Conclusions

- *Presented today, signature analysis in the High mass Higgs Program from both DØ and CDF experiments.*

- *Inclusion of large dataset with improvements in analysis methods were presented.*

- *Reached SM sensitivity !!*

- *Exciting times for the Higgs searches at Tevatron.*

- *Not done yet - Still room for improvements :*
  *-- Larger dataset available to analyze ~ 10 $fb^{-1}$*
  *-- Improvement in Object Id's*
  *-- Smarter analysis techniques*
  *-- Adding more sub-channels.*

*Stay tuned for more exciting results from Tevatron Higgs Searches*

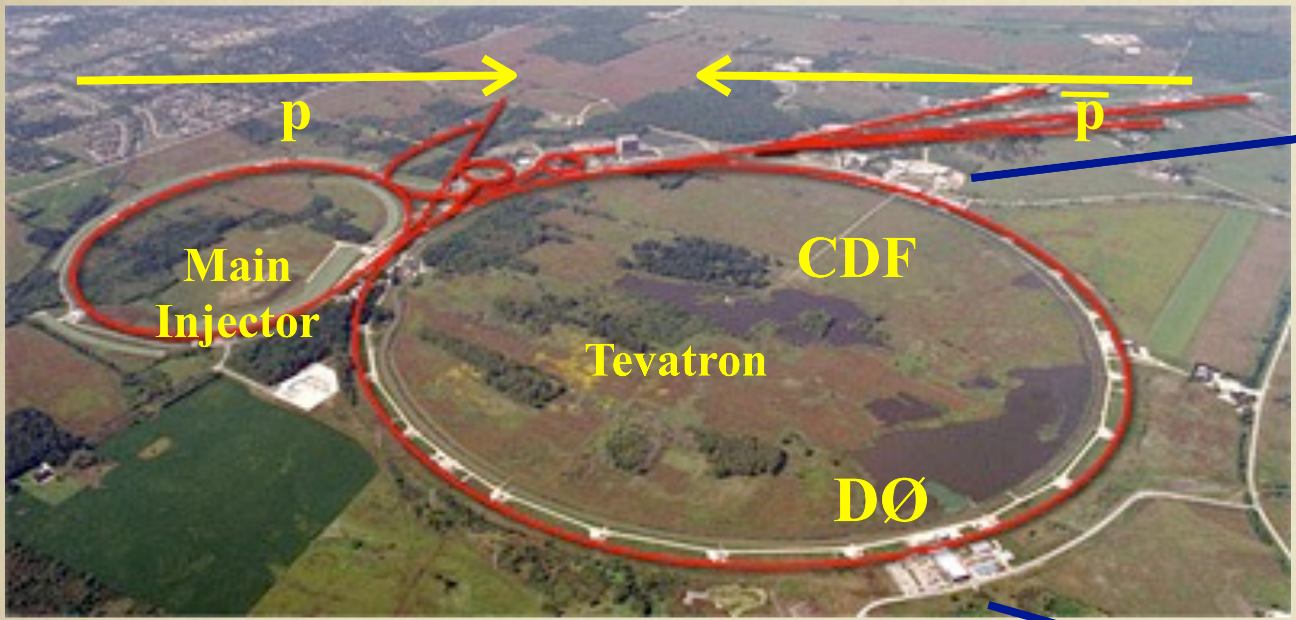
*Thanks !*

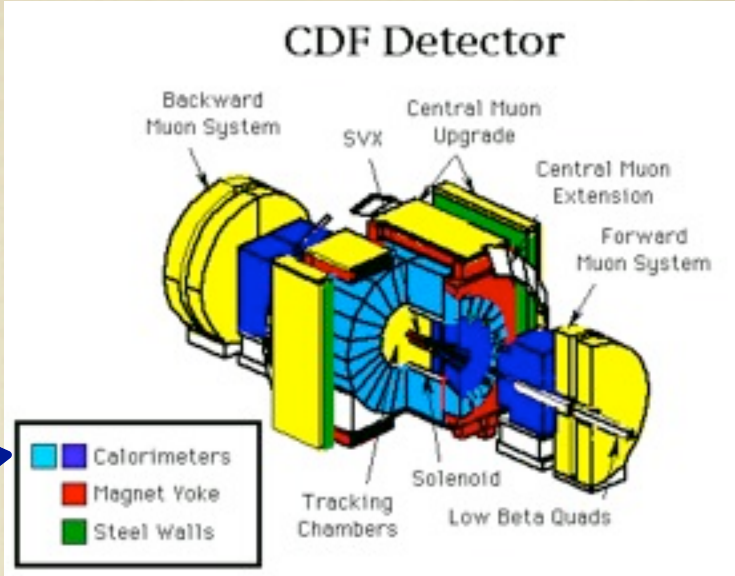
# Back Up Slides

# Tevatron Accelerator Complex

• A chain of accelerator is employed to produce ppbar collisions at sqrt(s)=1.96 TeV.

• The proton-antiproton collisions at the Tevatron gives rise to ~ 2 million collisions per second at two interaction points DØ and CDF.



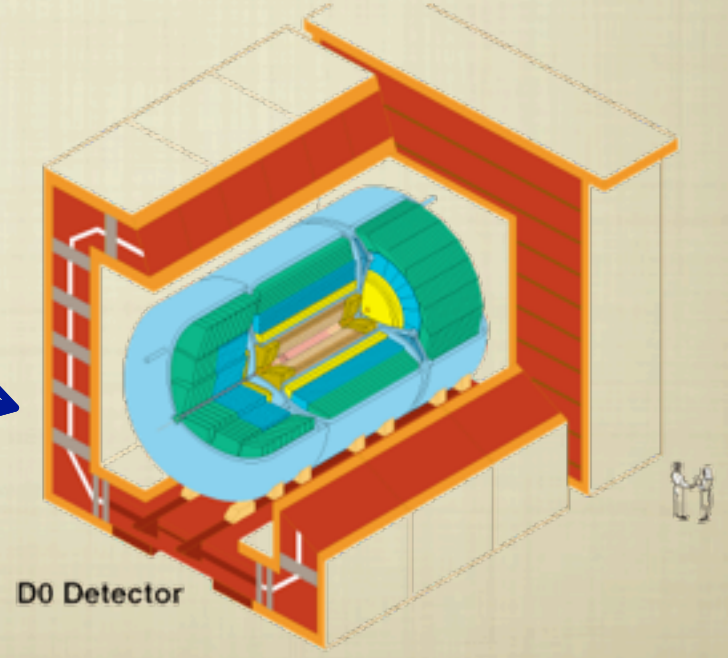




• At these points two multipurpose HEP detectors are housed. Their important sub-components are:

*-- Silicon tracker*

*-- calorimeter*

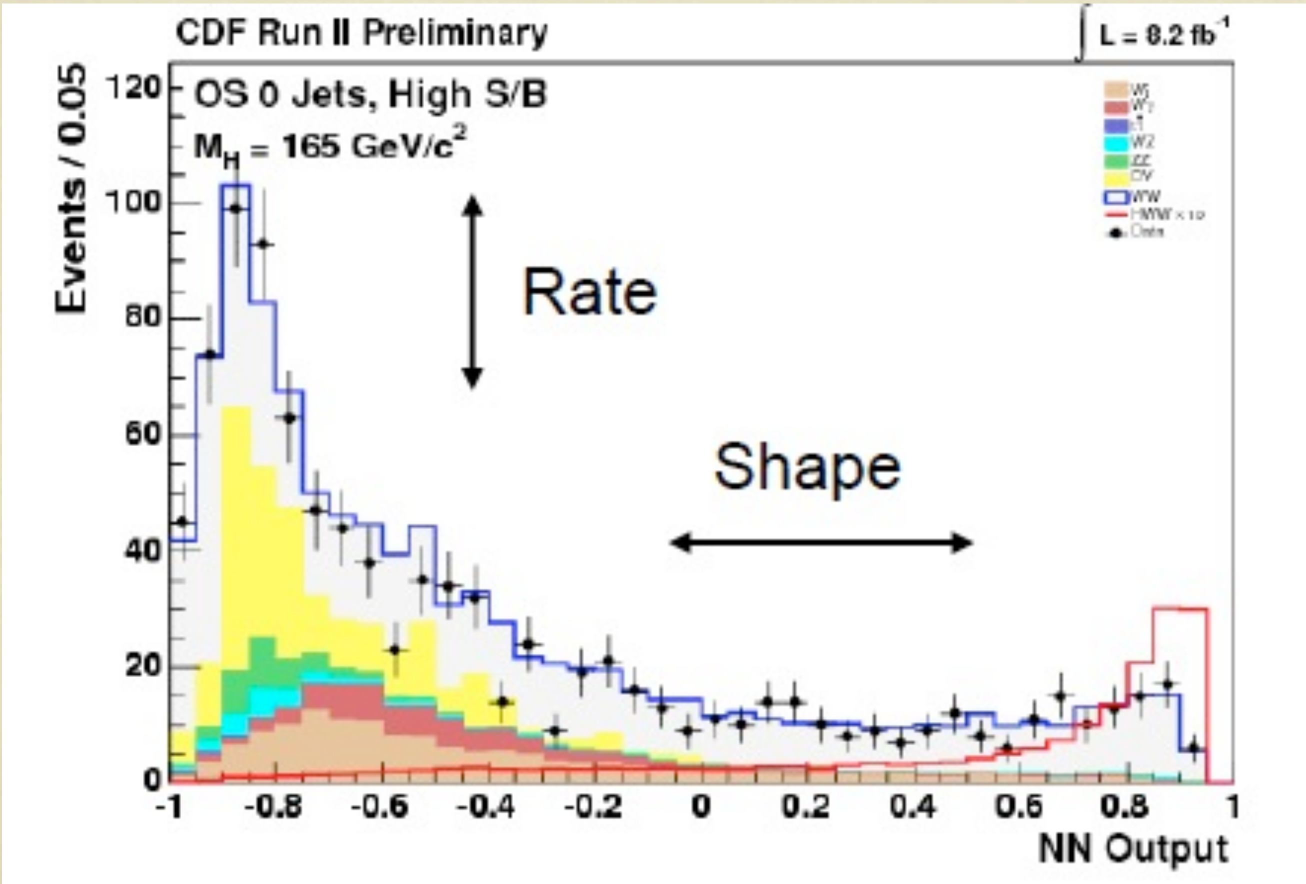
*-- Muon Chambers*



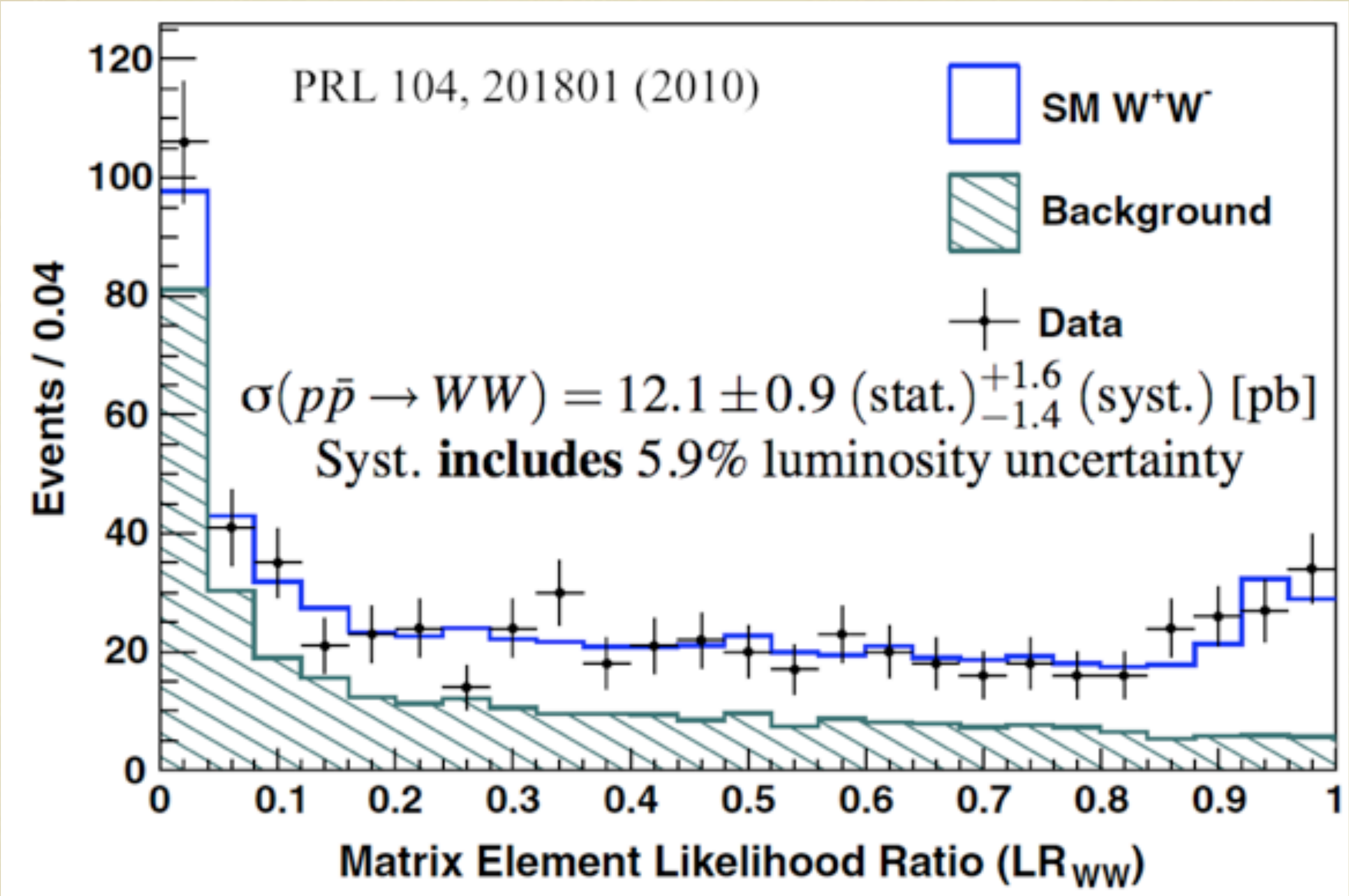
# Systematic Uncertainties ..(1)

- Two class of systematics considered in the analysis:
  - → ***affecting shape of the signal/backgrounds in the final discriminant output***
  - → ***affecting the rate/normalization of the background/signal process in the final output.***

- The uncertainties are accounted for as nuisance parameters in the limit calculations.



# MVA Cross-Check



# Matrix Element

The probability density for any given mode m

$$P_m(x_{obs}) = \frac{1}{<\sigma_m>} \int \frac{d\sigma_m^{th}(y)}{dy} \epsilon(y) G(x_{obs}, y) dy$$

| | |
|---|---|
| $x_{obs}$ | are the observed "leptons" and $\vec{\not{E}}_T$, |
| $y$ | are the true lepton four-vectors (including neutrinos), |
| $\sigma_m^{th}$ | is the leading-order theoretical calculation of the cross-section for mode $m$, |
| $\epsilon(y)$ | is the total event efficiency $\times$ acceptance, |
| $G(x_{obs}, y)$ | is an analytic model of resolution effects, and |
| $\frac{1}{<\sigma_m>}$ | is the normalization. |

Event probability densities used to construct discriminant:

$$LR_S(x_{obs}) \equiv \frac{P_S(x_{obs})}{P_S(x_{obs}) + \Sigma_i k_i P_i(x_{obs})},$$ CDF Note 10432